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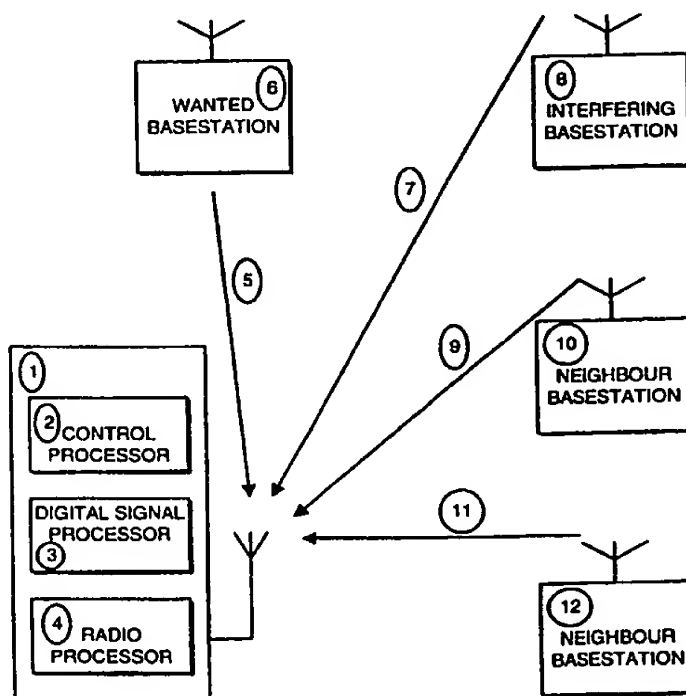
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(54) Title: HANDOVER CONTROL IN A RADIO COMMUNICATION SYSTEM

(57) Abstract

A radio communications system comprising a mobile radio unit (1), and a number of base stations (6, 8, 10 and 12). The mobile unit (1) comprises, *inter alia*, a control processor (2), a digital signal processor (3) and a radio processor (4). The mobile unit 1 receives a wanted signal (5) from its serving or wanted base station (6). However, when there is an interfering signal (7) coming from an interfering base station (8), the mobile unit can attempt handover to one of two neighbouring base stations (10, 12) which offer suitable available alternative, neighbouring signals (9, 11). The mobile unit (1) monitors the signal level and wanted carrier signal to interference ratio of the wanted signal (5) from the serving base station (6), and the signal levels and the carrier to interference ratios of the signals (9, 11) of the neighbour base stations (10, 12), and makes a decision as to whether to perform a handover, and to which base station to handover to, on the basis of the carrier to interference ratios and the signal levels of the signals from the serving and neighbouring base stations.



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## HANDOVER CONTROL IN A RADIO COMMUNICATION SYSTEM.

5           The present invention relates to a radio  
communications system and in particular to a method of  
and apparatus for controlling handover in a mobile radio  
communications system, which is particularly, but not  
exclusively, suited to controlling handover in the TETRA  
10 (TERrestrial Trunked RADIO) system.

Mobile radio communications systems, such as  
private mobile radio systems and cellular phone systems,  
typically comprise several base stations arranged in a  
cellular fashion, with each base station being intended  
15 to serve a particular geographical area or 'cell'. The  
mobile radio units of the system are transferred or  
handed over from base station to base station as they  
move between cells. Handover changes the base station  
that the mobile unit is using and is done to try to  
20 provide seamless coverage and maintain or improve radio  
signal quality as the mobile unit moves around within  
the cellular network.

Decisions on when to attempt handover are typically  
based on the strengths of the signals on radio channels  
25 that the mobile unit has access to, as signal strength  
is a convenient and readily determinable parameter that  
handovers can be based on. For example, a mobile unit  
could be handed over to a neighbouring base station  
whenever it is determined that the received signal  
30 strength available from the neighbouring base station is  
greater than the strength of the signal being received  
from the mobile unit's current serving base station.

The Applicants have recognised that in many mobile  
radio communications systems, the received signal  
35 quality as perceived by a user can be particularly  
affected by interference occurring in the system. For  
example, cellular radio communications systems often re-

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use radio frequencies to allow more extensive geographical coverage with a small set of frequencies. However, two base stations that are close to each other and using the same frequency can interfere with each other. This is known as co-channel interference, and can degrade the received signal as perceived by a user. However, the Applicants have found that signal strength measurements cannot readily distinguish interference effects and in particular such co-channel interference. This can make handover decisions based on signal strength measurements alone unreliable.

According to a first aspect of the present invention, there is provided a method of controlling handover of a mobile radio unit between base stations in a radio communications system, comprising:

- estimating the level of interference on the radio channel via which the mobile radio unit is communicating with the base station which is currently serving the mobile radio unit;
- estimating for each of one or more other base stations of the system, the level of interference on a radio channel available to the mobile radio unit from that base station; and
- controlling handover of the mobile radio unit from its serving base station to the other base station or one of the other base stations on the basis of the estimated levels of interference on the radio channels of the serving base station and the other base station or stations.

According to a second aspect of the present invention, there is provided an apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communications system, comprising:

- means for estimating the level of interference on the radio channel between the mobile radio unit and the base station which is currently serving the mobile radio

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unit;

means for estimating the level of interference on a radio channel available to the mobile radio unit from another base station of the radio communications system;

5 and

means for controlling handover of the mobile radio unit between the serving base station and the other base station on the basis of the estimated levels of interference on the radio channels of the serving and other base stations.

10 In the present invention, handover is controlled on the basis of the estimated level of interference on the wanted or available radio channels from plural base stations of the communications system (i.e. the channels carrying or that would carry the useful information that the user wishes to receive). In other words, the level of interference on the radio channels is used to determine handover.

20 The handover method and apparatus of the present invention is responsive to interference effects, and thus provides an improved handover process which is less susceptible to errors due to, for example, co-channel interference and can provide a better perceived signal quality to a user. It has also been found in particular to be usable to improve frequency re-use in a cellular radio communications system. This is because the present invention takes account of interference for handover decisions and can thus maintain acceptable performance as perceived by a user with higher levels of interference present. This permits the system of the present invention to operate with higher levels of e.g. co-channel interference allowed, and thus re-use frequencies more extensively. Also, the system of the present invention will avoid mobile units using carriers which suffer from high interference levels, but still have strong signal strengths, in contrast to systems where handover is based only on signal strength which

would select such carriers preferentially. Thus in the system of the present invention there is less need to employ larger numbers of frequencies to reduce co-channel interference to try to prevent such carriers arising. This again permits greater frequency re-use.

The estimated interference levels of the serving and other base stations' channels can be used to control and determine handover as desired. They are preferably used to decide whether or not to attempt handover, and most preferably to then decide which other base station to handover to, with a handover attempt then proceeding as normal for the system in question if it is determined that a handover attempt should be made. The handover attempt decisions are preferably made by comparing the estimated interference levels for the serving base station's channel with the estimated interference levels of the other base stations' channels. For example, a handover attempt could be made if another base station offers a channel with a lower estimated level of interference.

The handover decision could be based on the estimated interference levels alone or on the estimated interference levels and other factors or criteria, such as another parameter or parameters indicative of radio performance.

Suitable such parameters would include the signal time delay (a measure of the mobile unit's distance from the base station), the signal strength, or any other parameter typically used in handover procedures. Further examples include the system's knowledge of loading on particular radio sites, or the speed at which the mobile unit is travelling through the area in question (e.g. a fast moving mobile should preferably not use a small radio cell if a large one is available, as otherwise another handover will be required very soon). The mobile's speed can be estimated from historical timing information on previous handovers,



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etc., as is known in the art.

In a particularly preferred such embodiment the handover decision is based on the estimated signal to interference levels and the determined signal strengths (e.g. received signal strength indications, RSSI, in TETRA, or power levels) of the serving signal and the signal or signals available from the other base station or stations. This further refines the handover process and, for example, can be used to drive handover attempts to improve signal levels, even when little or no interference is present, or to ensure handover when the wanted signal level provided by the serving base station is too low, irrespective of the interference present.

In this embodiment, the handover decision is again preferably based on a comparison of the interference levels of the serving base and other base stations and comparison of the strengths of the various signals. In such an arrangement an attempt to hand the mobile unit over from the serving base station to another base station is preferably made if the signal available from the other base station has a greater signal strength and no worse (or at least not known to be worse) an estimated interference level than the serving base station signal. Additionally or alternatively, the arrangement can be such that a handover attempt will be made to another available base station offering a signal of worse signal strength, but better estimated interference level. In this latter arrangement, preferably a handover attempt only occurs if the other base station still provides an adequate signal strength (e.g. it exceeds a predetermined threshold level) for communication.

Alternatively or additionally, the ratio of the signal strength to interference level could be considered, with handover being attempted, e.g., if appropriate, to a channel offering a higher ratio. This would allow handover from a cell with a high signal

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strength and a high interference level to a cell with a lower signal strength but a better overall signal strength to interference level ratio.

5 In a particularly preferred embodiment of the present invention, it is first decided whether handover might be necessary and only if handover might be necessary is a decision made as to whether and to which base station, to attempt handover to. The decision as to whether handover might be necessary can be based on, for  
10 example, the interference level and/or the signal strength of the serving base station signal. Preferably, it is decided that handover might be necessary if one or both of these parameters falls below a particular, preferably predetermined, threshold level,  
15 for example when the RSSI indicates a carrier level less than -90dBm in a TETRA system. Once it is decided that handover might be required, then a decision to attempt handover and as to the base station to handover to can be made as discussed above.

20 Where the handover decision is based on the comparison of estimated interference levels (and other parameters such as signal strengths, where appropriate), handover is preferably only attempted if the other base station's estimated interference level is less than the  
25 serving base station's estimated interference level (and/or the other base station's signal strength is greater than the serving base station's signal strength, if appropriate) by a particular, preferably predetermined, amount greater than zero, i.e. it is less  
30 than or greater than, as appropriate, the serving base station's relevant parameter by a predetermined margin. This margin acts as a hysteresis margin and helps to prevent "ping-pong" effects where a mobile unit  
35 frequently hands between base stations due to only small changes in interference level and/or strength.

The margin can be selected as desired, and could be expressed as a percentage or absolute value of, for

quency and spacing of the samples. The interference level value is determined can be as desired, e.g. to achieve the required time period allowed to produce a reliable estimate and/or the number necessary to produce a reliable estimate. Preferably, the samples are preferably regular and preferably taken at regular time intervals, e.g. every second. For example, to take into account the effect of fading, the samples could be distributed over a range of 100 to 200 radio carrier wavelengths. At typical vehicle speeds at 400 km/h, it would be convenient to take samples every 100 to 200 wavelengths.

The number of sampled interference level values in the set of which the distribution is determined can also be selected as desired. The number of samples may be predetermined. There should be a sufficient number of values for their distribution to provide a reliable estimate, but the greater the number of values, the longer the interference level estimation process takes. A set of ten or more samples is preferred, to ensure adequate statistical reliability.

The upper limit on the number of samples is determined by the time it takes to collect the samples.

For a reasonable response, a collection time of a few seconds or less is preferred.

The distribution of interference level values in the set can be assessed as desired.

One way that the values in the set are assessed is by sorting them across a range of the interference level values. The values are then considered. In a particularly preferred embodiment, the distribution is assessed by determining the range of determined values in the set for each of a plurality of particular range values. This sorting of the

example, the parameter in question. The higher the margin, the less sensitive is the handover process, but the lower the margin the greater becomes the "ping-pong" effect. Examples of margin values are 10dB. In a preferred embodiment the size of the margin is varied with time after the last handover in a predetermined manner. Most preferably the margin is decreased after a predetermined time period has elapsed since the last handover. For example, a margin could be applied immediately after a handover (to help to stop ping-ponging), but after a predetermined time thereafter (e.g. a few seconds) the margin is reduced (preferably progressively and stepwise) to a lower value to increase the sensitivity of the handover procedure. For example, for the first 10 seconds after a handover the margin could be set to 15dB, then to 10dB, then to 5dB, and 60 seconds after a handover, the margin could be reduced to 3dB and would remain until a new handover took place.

The interference levels of the channels served by the serving and other base stations can be estimated in a manner known in the art. It would normally involve taking a sample or samples of the received signals and considering the interference level of each sample or samples.

The overall combined interference level can be estimated, or just one type of interference, e.g. channel interference, could be considered.

The interference level estimate could be based on the instantaneous estimated interference level of a single sample of a signal on a channel, but more preferably for the other (non-serving) base stations it is based on the interference levels of a set of samples of a signal determined over an extended period. For example the average of a set of two or more instantaneous estimated interference level values (e.g. 10 values), for example taken over a predetermined

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be used to provide an overall interference level estimate for use in the handover procedure. (interference levels over a period of time and interference history), a better indication of freedom from interference or otherwise obtained. This gives a better indication of the signal quality and therefore a handover procedure as it makes direct channels that will provide better communications over extended periods of time and communications.

Particularly preferred such embodiment is a level estimate for use in the handover procedure based on the distribution of a set of sampled and instantaneous estimated interference level values. Thus the present invention preferably comprises steps of or means for determining an overall interference level estimate for each radio channel. Samples of a signal on the radio channel are used to determine the distribution of the values in the set of the determined interference level values.

Experiments have found that the way that the distribution of sampled interference levels are determined and spread differs for different overall interference levels, such that the distribution of interference level values can be used as an indication to estimate the level of the interference in the radio channel. However, because the distribution of interference level values is being used, the estimate is less susceptible to error from abnormal sample values. It is believed that the present embodiment provides a method of estimating radio channel interference level in a mobile radio system, and in particular a method of estimating interference level to be rapidly, but accurately estimated using a relatively small number

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determined values in the set into plural ranges, in a particularly convenient way of representing the distribution for subsequent analysis and estimation process. It effectively estimates the probability density function of the interference level values in the set (i.e. the probability of interference level having a particular value). The number of values in a range, divided by the total number of values in the set, is the probability of interference level value falling within that range.

The number and size of the ranges of interference level values to be used can be selected. The number of ranges would normally be predetermined. The ranges could, for example, be defined by the value of the interference level being greater than or less than a particular value, or being between two particular values. More ranges are more accurate, but increase calculation complexity. Three has been found to be a suitable number to give a useful estimate of the interference level.

The overall interference level estimate is preferably estimated by comparing the distribution of values in the sampled set with one or more reference distributions of values of the interference level, and making the estimation on the basis of the comparison. Preferably the comparison is made with preferably three or more, predetermined reference interference level values, each corresponding to a particular, different overall interference level. The interference level of the sampled radio channel is determined to be that of the reference distribution which its sampled set distribution most closely matches. The predetermined reference comparison distributions can conveniently be stored in memory means.

The number of predetermined reference distributions for comparison can be selected as desired. As the number of reference distributions increase the usefulness of

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estimation, but are more susceptible to erroneous estimation, whereas fewer comparison distributions make the process less useful. Three comparison distributions, corresponding to "good", "neither" and "bad" overall interference levels, have been found to provide a useful estimation function.

The reference distributions are preferably represented in a manner corresponding to the way in which the distribution of interference level values in the sampled set of values is to be assessed, as this makes the comparison process more straightforward.

Thus, in a particularly preferred embodiment, where the distribution of values for the sampled radio signal is assessed by determining the number of values in the set of sampled interference level values falling within particular value ranges, the comparison reference distributions each comprise a set of numbers representing the probability of the interference level value falling within the same particular value ranges for a signal of the overall interference level that the reference distribution represents. Most preferably, where a predetermined number of sampled values is used for the or each set to be analysed, the comparison distributions comprise the number of the values in a set of that predetermined number of values that should fall within each of the particular ranges for a signal of the overall interference level that the reference distribution represents.

These arrangements make the comparison process particularly straightforward, since the closest comparison distribution can be found by comparing directly the numbers in the comparison distribution with the number of values in each range determined for the set of sampled values. The closest comparison distribution can be found, for example, by determining which comparison distribution has the minimum estimated mean square error with the sampled set value

distribution.

It is believed that using the distribution of a set of sampled parameter values as a basis for controlling handover is advantageous in its own right. Thus,  
5 according to a third aspect of the present invention, there is provided a method of controlling handover of a mobile radio unit between base stations in a radio communication system, comprising:

10 determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel via which the mobile radio unit is communicating with the base station which is currently serving the mobile radio unit;

15 determining the distribution of the values in a set of two or more of the determined parameter values;

determining for each of one or more other base stations of the system, the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on a radio channel available to the  
20 mobile radio unit from that base station;

determining, for each of the other base stations, the distribution of the values in a set of two or more of the determined parameter values for that other base station; and

25 controlling handover of the mobile radio unit from its serving base station to the other base station or one of the other base stations on the basis of the determined parameter value distributions for the radio channels of the serving base station and the other base station or stations.  
30

According to a fourth aspect of the present invention, there is provided an apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communication system,  
35 comprising:

means for determining the value of a parameter indicative of signal quality for each of a plurality of

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samples of a signal on the radio channel between the mobile radio unit and the base station which is currently serving the mobile radio unit;

5 means for determining the distribution of the values in a set of two or more of the determined parameter values;

10 means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on a radio channel available to the mobile radio unit from another base station of the radio communications systems;

means for determining the distribution of the values in a set of two or more of the determined parameter values for the other base station; and

15 means for controlling handover of the mobile radio unit between the serving base station and the other base station on the basis of the determined parameter value distributions for the radio channels of the serving and other base stations.

20 In these third and fourth aspects of the present invention, the parameter indicative of signal quality is preferably an interference level estimate or the carrier to interference ratio, but can instead be any other parameter indicative of signal quality known in the art, 25 such as the received signal strength, or the signal to noise ratio, if desired.

In all of the above embodiments, the absolute value of the interference in each signal sample could be estimated, for example, by subtracting an estimate of 30 the wanted received signal based on the detected data stream to determine the residual interference signal.

However, preferably the degree or extent of interference relative to the wanted or carrier signal is estimated, for example by estimating the carrier to 35 interference ratio, C/I, on each channel. The ratio could be measured directly, e.g. by measuring the carrier to interference ratio, C/I, of the channel or

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channels (this could be achieved, for example, if the wanted and unwanted transmissions were intermittent, allowing the wanted and then unwanted powers to be each independently measured), or could be estimated by measuring a parameter indicative of the carrier to interference ratio, such as the uncoded bit error rate (i.e. the natural bit error rate of the signal before any corrections are made (e.g. using the channel coding included in the signal data)) of a wanted carrier on the channel. (The uncoded bit error rate is preferred because it is more sensitive to channel problems, as any processing of the raw code could remove errors and therefore give a less reliable indicator.) The bit error rate can be determined, as is known in the art, by, for example, comparison of an actual received bit sequence with the known transmitted sequence, e.g. training sequence correlation, or by using forward error code information such as checksums or cyclic redundancy check codes in the received signal.

In a particularly preferred embodiment, the carrier to interference ratio is estimated by determining the variation of a set of two or more sampled instantaneous estimated values for a given or particular parameter for a signal on the radio channel. Thus the present invention preferably further comprises steps of or means for determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel; and determining the variation of a set of two or more of the determined parameter values.

The Applicants have recognised that the variation of a set of determined values of a particular parameter for a radio signal gives an indication of the consistency of the signal over the set of samples, and can therefore be used as an indicator of interference level. The variation will depend upon both signal fading and any high-energy interference which is increasing the received signal energy, and thus is sensitive to the



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effects of interference (e.g. co-channel and adjacent channel interference and narrow band jamming), in addition to additive white Gaussian noise. Furthermore, determining the variation does not involve the comparison of known signal sequences, and thus does not require any prior knowledge of what has been transmitted nor need any synchronisation between transmitter and receiver.

The particular parameter, the instantaneous values and variation of which are to be determined, should comprise a parameter that is responsive to interference effects and the variation of which will give a measure of the carrier to interference ratio. It is preferably predetermined.

In a particularly preferred embodiment the selected particular parameter is one that would, in an ideal signal, be substantially identical for each sample of the signal, as then any variation in the parameter value will be due substantially to signal degradation or distortion, i.e. quality loss.

The Applicants have recognised that in many radio communication systems, the modulation technique used imparts to the carrier wave characteristics which at the instant of modulation are common to every sample or a particular set of samples of the signal on the radio channel. For example, in analogue systems, the radio signal may be modulated to initially have one or more constant parameters. In FM (frequency modulation) the amplitude of each sample of the signal is set to be the same and in AM (amplitude modulation) the relative phase of the signal is set to be the same.

In digital modulation, samples, and in particular symbols (i.e. the discrete individual states to which the modulated signal is constrained at periodic intervals, as is known in the art), of the signal are also initially modulated to have one or more identical, common characteristics or parameters. For example, each

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symbol may be modulated to have the same initial amplitude relative to the carrier wave. Alternatively or additionally each symbol may be initially modulated to have one of a set of predetermined values of a particular parameter or parameters, which value or values are then varied relative to each other for one or more symbols in a predetermined manner by the modulation, such that removal of the known modulation induced differences would leave each symbol with the same value for that particular parameter or parameters. An example of this could be the phase of each symbol relative to the carrier wave, which could be identical when the symbols are demodulated or mapped to a common phase quadrant so as to remove modulation-induced phase differences.

Thus the particular parameter, the variation of which is to be considered, could, for example, comprise the amplitude of each sample, or a phase measurement for each sample, relative to the carrier wave.

In an ideal signal these common characteristics or parameters would remain unchanged (and thus identical) during transmission. However, in practice, these common characteristics are distorted or changed by different amounts during transmission. Thus by looking at the variation of the nominally common characteristics (e.g. sampled signal amplitude) over a set of samples of the received signal, a particularly good indication of the distortion induced in the transmitted signal, and thus the signal quality, can be obtained, and using only a relative small number of samples.

The samples of which the particular parameter values are to be determined can be selected (e.g. as regards their spacing in time) as desired, as can the number of determined particular parameter values to be used in the set of which the variation is to be considered. Preferably, the set comprises a predetermined number of parameter values, and preferably

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at least sufficient values to average out variations caused by Gaussian noise, and, where appropriate, most preferably sufficient values to average out Rayleigh fading. The spacing and timing of the samples, and the number in a set, should be such as to provide a practically useful and statistically reliable result (e.g. to avoid sampling over too long a period for a given set which might lead to errors induced by users deliberately changing the power of their signals), as will be appreciated by those skilled in the art.

In a particular preferred embodiment the samples, the particular parameter values of which are to be determined, are selected to ensure that the parameter value being considered would be substantially identical for each sample in an ideal signal. Thus where a digitally modulated signal is being analysed, the samples preferably comprise symbols, and most preferably immediately successive symbols, of the digitally modulated signal.

The particular parameter value for each sample can be determined in any suitable manner known in the art. For example, the sampled symbols of a digitally modulated phase-shift keyed signal can be demodulated (or differentially demodulated, if differential phase-shift keying is used, such as would be the case in the TETRA system) or mapped to give them notionally common characteristics, (e.g. phase values), i.e. to remove any modulation induced parameter, e.g. phase, differences, and the variation of one or more of the parameters, such as amplitude or phase of the so mapped or demodulated signals then analysed. This mapping could be done by, e.g. taking the modulus of the real and imaginary parts of each symbol, and/or by changing the determined instantaneous parameter value in a predetermined manner based on the determined instantaneous value.

The variation of the set of determined particular

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parameter values can be determined in any suitable manner. For example, the extent of deviation of the values from a mean, modal or middle value, the range of the values, the difference between two selected values (e.g. the highest and lowest), or the standard deviation of the set of values could be used to indicate and represent the variation.

In one preferred embodiment, the variation is determined by calculating the variance of the set of the determined particular parameter values. This is a particularly suitable way of determining the variation of a set of parameter values. Thus the apparatus of the present invention preferably comprises means for calculating the variance of the set of the determined particular parameter values. The variance of the set of determined parameter values can be calculated using known statistical techniques.

In another preferred embodiment, the variation of the set of sampled values is determined by considering the error of each value from its expected value and then considering the errors of a set of sampled values. For example, by statistical analysis, such as taking the mean or modal error value, or considering the variation (e.g. variance or standard deviation) of the error values, a measure of the variation of the parameter values can be obtained.

The error value for each sample can be derived as desired. It is preferably the difference between the expected instantaneous parameter value (e.g. amplitude or phase) (which value would normally be predetermined by the modulation technique being used) and the observed determined value of that parameter for that sample. In a digitally modulated signal, the samples should be symbols of the signal, and thus the error value is preferably the difference between the expected instantaneous amplitude or phase of a symbol of that type and the observed amplitude or phase value,

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respectively, for the symbol.

In a particularly preferred embodiment where the quality of a digitally modulated radio channel is to be estimated, the present invention preferably comprises  
5 steps of or means for measuring the amplitude and/or phase of each of a plurality of symbols in a digitally modulated signal on the radio channel; and determining the variation of a set of two or more of the measured amplitude and/or phase values.

10 This embodiment of the present invention preferably further comprises steps of or means for removing any modulation induced phase and/or amplitude differences between the symbols in the set to provide a modified set of symbols having nominally identical amplitudes and  
15 phases, and then measuring the amplitude and/or phase of each symbol in the modified set of symbols and using these measurements for the variation determination.

The determined variation measurements can be converted to suitable carrier to interference level  
20 estimates as desired. For example, they can be converted into a corresponding bit error rate measurement, for example, by relating the variation results to equivalent bit error rates (e.g. experimentally or by using a simulation), and  
25 determining therefrom a relationship, curve-fit or look-up table from which the corresponding bit error rates can in future be derived.

In a particularly preferred embodiment the determined variation measurements are used to form a set  
30 the distribution of which is then considered (as discussed above) to estimate the overall interference level. In this arrangement, each determined variation value or measurement is used as one sampled value of the interference level, and plural such variation values are  
35 used to form a set whose distribution is then determined to provide an estimate of the overall interference levels. This is particularly advantageous because the

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variation result gives a good microscopic indication of the interference level and the distribution of the variation values a good macroscopic indication of the overall interference level. Indeed, using the  
5 distribution of a set of variation values to control handover is considered to be advantageous in its own right.

Thus, according to a fifth aspect of the present invention, there is provided a method of controlling  
10 handover of a mobile radio unit between base stations in a radio communication system, comprising:

determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel via which the  
15 mobile radio unit is communicating with the base station which is currently serving the mobile radio unit;

determining the variation of a set of two or more of the determined parameter values;

determining the variation of at least one further set of two or more of the determined parameter values;  
20

determining the distribution of the values in a set of two or more of the determined variation values;

determining for each of one or more other base stations of the system, the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on a radio channel available to the mobile radio unit from that base station;  
25

determining, for each of the other base stations, the variation of a set of two or more of the determined parameter values, and the variation of at least one further set of two or more of the determined parameter values, for that other base station;  
30

determining the distribution of the values in a set of two or more of the determined variation values for each of the other base stations; and  
35

controlling handover of the mobile radio unit from its serving base station to the other base station or

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one of the other base stations on the basis of the determined variation value distributions for the radio channels of the serving base station and the other base station or stations.

5           According to a sixth aspect of the present invention, there is provided an apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communication system, comprising:

10           means for determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel between the mobile radio unit and the base station which is currently serving the mobile radio unit;

15           means for determining, for each of two or more sets of two or more of the determined parameter values, the variation of the determined parameter values in the set;

            means for determining the distribution of the values in a set of two or more of the determined variation values;

20

            means for determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on a radio channel available to the mobile radio unit from another base station of the radio communications systems;

25

            means for determining, for each of two or more sets of two or more of the determined parameter values for the other base station, the variation of the determined parameter values in the set;

30           means for determining the distribution of the values in a set of two or more of the determined variation values for the other base station; and

            means for controlling handover of the mobile radio unit between the serving base station and the other base station on the basis of the determined variation value distributions for the radio channels of the serving and other base stations.

35

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The estimated interference level is preferably used to rank the channel as being in one of a plurality of predetermined 'quality' categories. For example, it could be ranked as being "good" or "bad" on the basis of a predetermined threshold or interference level for the ratio estimation parameter or indicator being used. In a particularly preferred such embodiment, the channel quality is classified on the basis of the distribution of a set of two or more sampled estimated interference levels discussed above. This provides a particularly effective and reliable way of estimating channel quality.

The channel quality classifications or ranks can then be easily used to determine handover, e.g. such that handover attempt will be made from a "bad" channel to a "good" channel, if available.

A further class of quality indication as being "unknown" can be included for occasions where it is not possible to estimate a base station's channel's interference level. A classification of "unknown" could, for example, be useful for classifying a carrier which the system has only recently started analysing (e.g. at switch-on). When the system has had time to average the channel quality, etc., it can give a more useful quality classification. An estimation that the channel quality is "unknown" could be used as desired in the handover process, e.g. such that handover would not be attempted to a base station providing a channel of "unknown" quality, or such that the handover to such a base station will only be attempted if the serving base station channel is "bad".

Preferably the interference level or quality of the serving base station's channel is estimated and a check as to whether handover is necessary made accordingly, at regular, preferably predetermined, intervals. A convenient interval in a TETRA system is 10s as it fits in well with the frame timing; intervals much longer



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than 60s could cause undesirable delays in handing over.

The interference levels of the other base stations' channels could be determined selectively, for example in response to a particular or predetermined trigger to do so (such as a decision that handover might be necessary), but preferably are monitored and determined at regular, preferably predetermined intervals, (particularly in a TETRA system), as this reduces response time when the channel quality deteriorates.

When required, the received signal strength of the serving and other base stations' signals can also be determined as is known in the art, for example by measuring the signal strength (e.g. power level or received signal strength indication (RSSI) in TETRA) of a sample of the signal, or of samples of the signal (e.g. by taking their average or considering their distribution).

The strength of the serving base station's signal, if required, is also preferably determined at regular intervals (e.g. at the same intervals as the interference level of the serving base station's channel is estimated). The signal strengths of the other base stations could again be estimated selectively, for example in response to a predetermined trigger to do so, but as for the interference levels of the other base stations they are preferably monitored at regular intervals.

The samples of the various signals for estimating the interference levels and determining any other signal parameters can be taken as desired. In the TETRA system samples, particularly of the other base stations' signals, can be conveniently taken in the 18th frame of the TETRA signal since that frame is idle and not used for information or useful traffic.

The other base stations of the communications system whose channel interference levels (and strengths) are to be monitored can be selected as desired.

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Preferably they comprise the base stations neighbouring the serving base station. They could comprise all the base stations the cells of which immediately geographically neighbour the serving base station (which base stations can be estimated, for example, from stored historical information on previously handovers), or only a selected number of those base stations. Such a selection could, for example, be based on the direction of travel of the mobile radio unit.

Where two or more other base stations are available and being considered for handover, handover could be attempted to the first base station found to fulfil the criteria for a handover attempt, or a further selection could be made, for example on the basis of which of the suitable base stations provides the lowest estimated interference level (or highest quality) and/or highest signal strength, or on the basis of other factors such as the direction of travel of the mobile unit. The speed of the mobile unit could be another criterion. For example, fast moving mobiles should preferably be handed over to large cells if possible leaving small cells for pedestrians, etc. This is particularly applicable in cellular systems which use arrays of small pico-cells overlaid on the large macro-cells, such as might be used in busy places such as airports.

Handover attempts can be permitted whenever it is determined that handover may be necessary and/or a suitable handover target exists, or they could be arranged to operate more restrictively or selectively.

For example, handover attempts could be permitted only when a user has finished transmitting and receiving. This will minimise inconvenience to a user and reduce the level of handover signalling which the radio system's infrastructure has to deal with. Alternatively, handover attempts can be permitted during a call, and this will be desirable where calls are likely to be lengthy (e.g. of the order of several

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minutes), since in such situations it may not be desirable to postpone handover, as that may, for example, cause co-channel interference within the radio network. However, in such an embodiment, handover is preferably not attempted in cases where there is a significant probability that the call will drop as a result of the handover attempt. Such call dropping may be particularly likely if the mobile unit is handing over to another cellular network. Handover attempts can also be permitted when the mobile unit is idle and not involved in a call.

Handover attempts could also be prevented or restricted by other conditions being met or events occurring. For example, a user could be permitted to selectively disable or override handover attempts. The handover procedure could also be arranged such that it will not override the selection of a user's preferred radio network or cause a change in radio network. In this latter arrangement, the handover process could further include a step of comparing the network type of the serving and other base stations, and be arranged to handover in preference to a base station of the same network as the serving base station and/or to prevent handover to a different network.

The handover procedure can also be arranged to only be performed if, from the user's point of view, the new base station in question offers no worse service features and functions than the serving base station. For example, handover attempts that override the selection of the user's preferred network, the selection of priority cells, the selection of a cell upon which a user may gain service features or functions, and/or the selection of an alternative cell if registration or authentication failure has occurred, could be forbidden.

In many cellular mobile radio communications networks, base stations are arranged in so-called location areas, and the mobile units register (and

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authenticate in secure systems) whenever they move into a new location area. In a particularly preferred embodiment of the present invention in such a network when the mobile unit registers on a new location area, the new registration is preferably assigned to both the new location area and the immediately preceding (if the mobile unit was previously registered) location area. This means that the mobile unit can freely "ping-pong" between the two base stations on the border of the location area without requiring further registration signalling. When it eventually roams across the location area and into a third location area, the registration from one of the first or second location areas can now be removed and the third location area will assign the registration on both the second or first, respectively, and third location areas. The mobile can once again "ping-pong" between the two base stations from the second or first and third location areas without generating further registration traffic. This approach allows location areas to be kept small in terms of the number of cells whilst reducing the amount of registration traffic.

The handover processes, etc, of the present invention may be performed by base stations or other components of the fixed radio network. Preferably, however, the signal measurements and estimates and handover decisions are made by the mobile radio unit which then advises the system of its desire to handover and its handover target accordingly. This reduces the need for processing power and time in the, e.g., base stations, does not require base stations to have receivers for listening to mobile radio units in adjoining cells and avoids the need to broadcast large numbers of signal measurements to base stations.

The methods in accordance with the present invention may be implemented at least partially using software e.g. computer programs. It will thus be seen

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that when viewed from a further aspect the present invention provides computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means. The invention  
5 also extends to a computer software carrier comprising such software which when used to operate a radio system comprising a digital computer causes in conjunction with said computer said system to carry out the steps of the method of the present invention. Such a computer  
10 software carrier could be a physical storage medium such as a ROM chip, CD ROM or disk, or could be a signal such as an electronic signal over wires, an optical signal or a radio signal such as to a satellite or the like.

It will further be appreciated that not all steps  
15 of the method of the invention need be carried out by computer software and thus from a further broad aspect the present invention provides computer software and such software installed on a computer software carrier for carrying out at least one of the steps of the  
20 methods set out hereinabove.

A preferred embodiment of the present invention will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 shows schematically a radio communications  
25 system;

Figure 2 shows a probability density function of burst errors for a TETRA signal having a 0.7% bit error rate;

Figure 3 shows a probability density function of  
30 burst errors for a TETRA signal having a 2% bit error rate;

Figure 4 shows a probability density function of burst errors for a TETRA signal having a 6% bit error rate;

35 Figure 5 shows an apparatus for determining the variation of a set of sampled parameter values;

Figure 6 shows a modulated  $\pi/4$  differential

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quaternary phase-shift keying modulated TETRA signal;

Figure 7 shows the demodulated form of the signal shown in Figure 6;

Figure 8 shows the demodulated constellation points of Figure 7 mapped to the first quadrant of the graph; and

Figure 9 shows the probability density function of the points on the graph in Figure 8; and

Figure 10 is a graph of signal power against time for an exemplary radio signal subjected to a Rayleigh fading envelope.

Figure 1 shows schematically a TETRA communications system that can be operated in accordance with the present invention comprising a mobile radio unit 1, and a number of base stations 6, 8, 10 and 12. Although only a single mobile unit and a few base stations are shown, the radio communications system could in practice comprise a much larger number of mobile units and base stations.

The mobile radio unit 1 is the device carried by a user that they use for radio communication to other users of the system via the base stations. The mobile unit 1 comprises, *inter alia*, a control processor 2, a digital signal processor 3 and a radio processor 4.

The control processor 2 is, *inter alia*, responsible for all of the decision making related to the handover process. It will collect information from the radio processor 4 and digital signal processor 3 of the mobile radio unit and based on this information and a handover procedure make decisions on handover attempts.

The digital signal processor 3 performs the signal processing necessary to make the radio function. The digital signal processor will also provide a wanted signal level to interference ratio (i.e. interference level) estimate for both the signal from the base station 6 serving the mobile unit and for the signals of neighbouring base stations 10, 12.

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The radio processor 4 includes the RF digital and analogue processing elements of the radio subsystems that permit the radio to function correctly. These elements include timing means, the receiver and the transmitter, as is known in the art.

All the components of the mobile radio unit can, for example, be embodied in a mobile radio unit for the TETRA system.

As shown schematically in Figure 1, the mobile unit 1 is currently receiving a wanted signal 5 from its serving or wanted base station 6 (the base station to which the mobile unit is currently attached). However, there is also an interfering signal 7 coming from an interfering base station 8. Signal 7 could, for example, be a signal that arrives on the same frequency as the serving base station signal. Such interference will result in a reduction in the quality of service for the signal received from the serving base station as perceived by a user, and, if the reduction is large enough, will trigger a handover attempt (i.e. an attempt to change the frequency and base station that the mobile unit 1 is using). This interference could, for example, be a consequence of the tight compact frequency reuse structure that is typically employed in radio communications networks.

Also shown are two neighbouring base stations 10, 12. These neighbouring base stations are in the immediate vicinity of the serving base station 6 and can offer suitable available alternative, neighbouring signals 9, 11 to the mobile unit 1. These neighbouring signals are the target signals to be used during a handover attempt.

The operation of the radio communications system in accordance with the present invention will now be described with reference to a TETRA system. However, it should be noted that the invention is equally applicable to other radio systems.

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In use, the TETRA mobile unit 1 will monitor the signal level and wanted carrier signal to interference ratio of the wanted signal 5 from the serving base station 6 (either during a call and/or when the mobile is in idle mode). The serving signal level is estimated from the received signal strength indication measurements formed in the radio processor 4 and passed to the control processor 2 via the digital signal processor 3.

The ratio of the serving carrier signal level to the interference level is also estimated and passed to the control processor 2 via the digital signal processor 3. The carrier to interference ratio estimation can be based on, for example, the bit error rate in the receiver or the carrier to interference ratio, C/I, (measured directly, if possible) of a sample of the signal. Another suitable carrier to interference ratio estimation process is to consider the variation of a set of determined instantaneous values of a particular parameter for a signal on the radio channel.

Figure 5 shows an apparatus 21 suitable for assessing the variation in parameter values of a physical TETRA channel, and in particular of a  $\pi/4$  differential quaternary phase-shift keying ( $\pi/4$  DQPSK) modulated signal, such as might be present on that channel.

The plot of a sequence of TETRA  $\pi/4$  DQPSK constellation points of an exemplary complex  $\pi/4$  DQPSK signal is shown in Figure 6. A signal 22 such as this is input to a differential demodulator 23 of the apparatus 21, in which a sequence of such constellation points,  $x$ , which may be described by:

$$\begin{aligned} n &= 1, \dots, N \\ x &= [x_1, x_2, x_3, \dots, x_N] \\ x_n &= i_n + j \cdot q_n \end{aligned}$$



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is differentially demodulated, as is known in the art, to produce a QPSK constellation like the one shown in Figure 7. The points in Figure 7 are the symbols of the signal (i.e. the parts of the signal which represent the data in the signal) and form the samples whose instantaneous parameter values (and their variation) are to be determined. The radius of the circle on which the constellation points lie (at the phases  $+\pi/4$ ,  $+3\pi/4$ ,  $-\pi/4$ ,  $-3\pi/4$ ) is proportional to the mean symbol energy  $\mu_p$ .

The sequence 24 of demodulated constellation points or symbols,  $y$ , is given, as is known in the art, by:

$$\begin{aligned}
 y &= [y_1, y_2, y_3, y_4, \dots, y_N] \\
 y_n &= x_n \cdot \text{Conjugate}(x_{n-1}) \\
 &= (i_n \cdot i_{n-1} + q_n \cdot q_{n-1}) + j \cdot (q_n \cdot i_{n-1} - i_n \cdot q_{n-1})
 \end{aligned}$$

Each demodulated constellation point comprises two orthogonal 'soft decisions' whose magnitude represents the instantaneous energy in the in-phase and quadrature-phase components of the signal samples.

The magnitudes of the instantaneous energies of the in-phase and quadrature-phase components of each demodulated constellation point in the sequence 24 of demodulated constellation points is then determined (this effectively maps the demodulated constellation points to the first quadrant to give a graph as shown in Figure 8) to generate the IQ scalar energy or symbol energy sequence,  $p$ :

$$\begin{aligned}
 p &= [p_1, p_2, p_3, p_4, \dots, p_{2N}] \\
 p_{2n-1} &= |\text{Re}\{y_n\}| \\
 p_{2n} &= |\text{Im}\{y_n\}|
 \end{aligned}$$

The variance  $\sigma^2$  of a set of the values in the scalar amplitude sequence can then be determined using standard

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statistical analysis:

$$\begin{aligned}
 \sigma^2 &= E[(p-\mu)^2] \\
 &= E[p^2] - 2E[p \cdot \mu] + E[\mu^2] \\
 5 \quad &= E[p^2] - 2\mu E[p] + \mu^2 \\
 &= E[p^2] - 2\mu^2 + \mu^2 \\
 &= E[p^2] - \mu^2 \\
 E[p^2] &= \Sigma(p_n^2/N) \\
 \mu &= \Sigma(p_n/N)
 \end{aligned}$$

10

where  $\mu$  is the mean symbol energy value of the number  $N$  of values in the set being used, and  $E[a] = \Sigma(a_n/N)$ .

15 A parameter indication of signal quality is given by the variance:

$$\sigma^2 = \Sigma(p_n^2/N) - (\Sigma(p_n/N))^2$$

20 A low value of  $\sigma^2$  indicates a good signal quality. Any additional in-band channel energy will increase  $\sigma^2$ , indicating a signal quality degradation. The signal quality indication therefore responds to co-channel interference, adjacent channel interference, and narrow band jamming in addition to additive white Gaussian noise.

25

The value of  $\sigma^2$  can be related to a bit error rate or carrier to interference ratio e.g. by performing analysis of actual radio channel data or simulations to derive look-up tables or predetermined relationships relating the two.

30

Figure 7 shows an exemplary probability density function for a symbol scalar amplitude sequence derived as described above.

35 Although in the above example the variance of the energy sequence was determined, as can be seen from Figure 8, there are four common characteristics or parameters of the mapped symbols. These are:

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- The distance of the mapped symbol from the origin
- The real part of the mapped symbol
- The imaginary part of the mapped symbol
- The phase of the angle subtended by the complex  
5 vector and the real axis.

The variation of any or all of these parameters could be considered, if desired.

The above example uses the variance of the set of  
10 parameter values as an indicator of signal quality.  
Other metrics indicative of the sampled values' variation can be used. One preferred such metric is to divide the mean of the set of values, e.g. symbol energy  $\mu_p$ , by the standard deviation of the set,  $\sigma$ . This gives  
15 a metric which is proportional to the mean symbol energy ( $E_s$ ) and inversely proportional to both the background noise ( $N_0$ ) and the interference ( $C_I$ ) levels, which will each serve to increase the standard deviation of the energy distribution:

20

$$\begin{aligned} Q &= \mu_p / \sigma_p \\ &\propto E_s / (N_0 + C_I) \end{aligned}$$

This is a good metric upon which to base estimates of  
25 bit error rate (e.g. by means of curve fitting or the use of lookup tables from simulation or actual situation analyses).

In the above embodiment the mean symbol energy,  $\mu_p$ , is preferably substantially constant throughout the set  
30 of symbols, as then any variation will be due to signal distortion. This has important implications when considering a practical radio communications system which may be subjected to a Rayleigh fading envelope, as shown for example, in Figure 10.

35 For example, the number of successive symbols  $N$ , over which  $\sigma^2$  is evaluated should be less than  $T_0/T_s$  (where  $T_0$  is the period over which the mean signal

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amplitude  $\mu_p$  is substantially constant and  $T_s$  is the symbol period), since over this set of symbols the mean symbol amplitude remains substantially constant.

5 If  $\sigma^2$  is evaluated over an over an extended period  $T_v$ , by taking one long symbol sequence of length  $(T_v/T_s)$  then the value  $\mu_p$  is no longer constant, and its variation would contribute to the signal quality metric  $\sigma^2$  and make it less reliable.

10 The time  $T_0$  over which to evaluate the metric  $\sigma^2$  can be selected as desired with these factors in mind. In a TETRA system, which is specified up to speeds of 200 kph, for example,  $Q_{IND}$  could be evaluated over  $N=16$  symbols, since at this speed the fading envelope is roughly constant over such a period.

15 Another suitable process for estimating the overall carrier to interference ratio for a set of sampled instantaneous values is to consider the distribution of a set of determined instantaneous interference level estimates. An example of such a process for a signal on  
20 a radio channel will now be described.

Firstly, a number of bit error rate probability density functions for known overall interference levels were determined to act as reference parameter value distributions.

25 This was done by simulating TETRA signals of known interference levels using the COSSAP TETRA system simulation package (COSSAP is a digital simulation software package licensed by Synopsis Inc., 700 East Middlefield Road, Mountain View, CA 94043, U.S.A.) and  
30 analysing the probability density function of the burst errors in those signals. Of course, other system simulation tools could be used, if desired. The simulation was configured to provide the bit error rates (BERs) of the bursts (i.e. packets) in the signals.

35 A number of simulations were performed using the standard fixed point library modelling the TETRA radio subsystem. The number of errors per burst for 20,000

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bursts were collected and dumped to a file. Individual files were created for a signals over range of carrier to interference, C/I, values corresponding to average BERs of 12%, 6%, 2%, 0.7% and 0.4%.

5        Using the Matlab numerical analysis package (again other packages could be used, if desired), the data from the 6%, 2% and 0.7% trials were used to generate a probability density function (PDF) for each of the trials. These trials were chosen because 2% BER  
10       represents a quality threshold in TETRA. To more accurately simulate the process that will occur in TETRA when neighbour cell monitoring is done during a full duplex call, only the burst in the 18th frame was considered.

15       The measured BERs from the simulation were grouped into three ranges or bins as shown in Table 1 below.

Table 1. Classification of Bins for the BER PDF analysis

20

Bin1	Bin2	Bin3
<0.7%	>=0.7%-<5.7%	>=5.7%

25       The number of value ranges was restricted to three because it was felt that satisfactory performance could be achieved with three thereby reducing the algorithmic complexity. More ranges could be used, if desired.

30       Probability density functions using these BER ranges were estimated for the 6% (representing a bad channel), 2% and 0.7% (representing a good channel) overall BER data. These PDFs are shown in Figure 2, Figure 3 and Figure 4.

35       From the form of the PDFs it is clear that the three different channel states exhibit bit error rate distributions or probability density functions that are different. The distribution of the bit error rate values can therefore be used as an overall interference

level "fingerprint" for comparison with a sampled channel.

Using the above PDFs, the number of sampled BER values of a signal of that quality from a set of ten  
5 sampled values expected to fall within the BER ranges (bins) shown in Table 1 were estimated to give reference bit error rate value distributions for the three channel interference level types "good", "neither" and "bad". These reference distributions are to be used as  
10 comparisons for the overall interference level estimation. (A set of ten sampled values was considered, because that was how many samples of the actual signal being analysed were to be used in the estimation process, but clearly other numbers of values  
15 could be considered.)

Table 2 shows the estimated value distributions:

Table 2. Coefficients for Channel "Fingerprint"

	BIN3	BIN2	BIN1
"Good"	0	1.0	9.0
"Neither"	1.5	1.5	7.0
"Bad"	2.5	1.5	5.0

The numbers of values differ slightly from the values that would be derived directly from the determined PDFs, because it was found that by varying  
20 slightly the number of values obtained from the PDF estimate for the channel quality a better overall result could be obtained. The amount to vary the number of values by can be determined experimentally by seeing which distributions of values work best in practice.  
30 (It is believed that the best set of numbers of values may not correspond directly to PDFs estimated from the simulations because of the effects of quantisation noise  
35

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when using only three ranges with ten samples per quality estimate. These factors are presumed to add a slight weighting to the numbers of values in each range that may be difficult to assess from a theoretical analysis.)

The value distributions or channel overall interference level "fingerprints" in Table 2 may be used to estimate which of the 3 interference level states a given radio channel is in, by comparing them with the distribution of a set of instantaneous interference level or BER values sampled from a radio signal on the radio channel.

Thus in this embodiment, the bit error rate of the packets (or bursts) in every 18th frame of a TETRA signal on a radio channel can then be determined and the distribution of a set of ten sampled bit error rate values compared with the reference bit error rate value distributions of Table 2. The distribution of the bit error rate values of the ten samples should be determined by sorting them into the three ranges described in Table 1, and then comparing this distribution with the three predetermined distributions described above by estimating the mean square error between it and each comparison reference distribution. The channel state represented by the comparison distribution that produced the minimum mean square error can then be selected as the current channel overall interference level state of the channel carrying the sampled signal.

Explicitly, the channel state is given by the value of  $j$  which minimises the following expression:

$$\text{Min} \left[ \sum_{i=1}^3 (x_i - y_{i,j})^2 \right] \quad j=1,2,3$$

Where  $x_i$  is the number of sampled BER values in the  $i^{\text{th}}$

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bin or range, and  $y_{i,j}$  are the predetermined number of values given in Table 2 where  $i$  is the bin or range number and  $j$  is the interference level identifier ( $j=1$ : Good;  $j=2$ : Neither;  $j=3$ : Bad).

5        In a particularly preferred arrangement, the samples whose distribution is to be assessed comprise the variation values (e.g. variance  $\sigma^2$ ) discussed above.

      To continuously monitor the interference level of a radio channel, this process can be repeatedly performed  
10        (e.g. in the present embodiment every 10s (which corresponds to 10 lots of the 18th frame), or by using a sliding process where the most recent 10 measurements are used).

      In a particularly preferred embodiment the overall  
15        carrier to interference ratio estimate for use in the handover process is based on the distribution of a set of variation values obtained from plural sets of sampled instantaneous interference level values. The variation of plural sets of signal samples can be used to provide  
20        corresponding bit error rates, and then the distribution of the set of bit error rate values used to provide an effective overall carrier to interference ratio estimate (and preferably to rank the channel as being 'good' or 'bad').

25        The received carrier level and/or carrier to interference ratio is monitored as discussed above, and when the received carrier level and/or carrier to interference ratio falls below a predetermined threshold level the mobile unit determines that a change in  
30        serving base station (i.e. a handover event) may be necessary. When the mobile unit 1 has made this determination, the control processor 2 will instruct the digital signal processor 3 to start to monitor the received signal strengths and the carrier to  
35        interference ratios of the signals 9, 11 of the neighbour base stations 10, 12.

      Upon receipt of this command from the control



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processor 2, the digital signal processor 3 instructs the radio processor 4 to start the collection of the neighbour base stations' signal information. As TETRA is a TDMA (time division multiple access) system that  
5 has 17 out of 18 frames for normal transmissions and 1 in 18 frames designed for other functions such as neighbour base station signal monitoring, one way to do this is for the radio processor 4 to retune the mobile unit 1 to the correct frequency for a neighbour base  
10 station signal measurement during this 18th frame. (Of course, sampling neighbour signals during the 18th frame is specific to the TETRA system, and different types of traffic and different transceiver designs could require or permit different and/or more frequent sampling of the  
15 neighbour signals. Different mobile radio systems would have different framing structures and so a different sampling methodology would apply there.)

Whilst on the correct frequency, the radio processor 4 will measure the received signal strengths  
20 from the neighbour base stations 10, 12, using any suitable technique known in the art. The measurements can be passed via analogue to digital converters to the digital signal processor 3 for further processing if required.

25 To measure the neighbour base stations' carrier to interference ratios, samples of the received neighbour signals 9, 11 are taken and passed from the radio processor 4 to the digital signal processor 3. A process, such as one of the processes described above  
30 for estimating the serving base station's carrier to interference ratio, can then be used by the digital signal processor 3 to estimate the carrier to interference ratios of the neighbour base stations' signals using the received data samples.

35 Thus the control processor 2 will be frequently receiving estimates of received signal strength and carrier to interference ratio from the serving base

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station 8 and intermittently from the neighbour base stations 10, 12 at a rate that is related to, for example, the recurrence of the 18th frame in a TETRA system (although more frequent samples are possible in a TETRA system, if desired, if an independent dedicated receiver for taking them is available).

The control processor 2 of the mobile radio unit will then make a decision on base station handover based on the data that is provided by the digital signal processor 3 and, for example, the radio processor 4 functions in the mobile radio unit. An example of suitable handover decision criteria that meet the basic requirement of achieving handover in a TETRA-like system is described below. Other criteria will exist for TETRA and other systems.

In this embodiment, the control processor 2 firstly maps, using a predetermined threshold, the carrier to interference ratio estimates from the digital signal processor 3 for each signal into a two state interpretation of the channel quality, either good or bad, to provide a quality indicator for each radio channel. The exact threshold for this designation of the channel quality can be selected as desired, and can be found, for example, by testing and field trials. It could be selectively adjustable by a user to allow in use optimisation of this parameter for the environment in which the mobile unit is operating.

Another method for mapping the carrier to interference ratio estimates to a channel quality classification is to use the distribution of the carrier to interference ratio estimates of a set of two or more samples of the signal discussed above to directly provide the classification.

The control processor 2 makes a decision as to whether to perform a handover, and to which frequency (i.e. signal or base station) to handover to, on the basis of whether the channel quality is good or bad and

the received signal strength indications, RSSI, of the signals from the serving and neighbouring base stations. Handover will be attempted if the received signal strength indication of the serving base station's signal is less than a predetermined reselect threshold (the signal level below which a handover must be attempted, which can be selected as desired), and then if any of the following conditions are met:

1. If the channel quality of the serving base station's signal is good and the neighbour signal's quality is good and the neighbour base station's received signal strength indication is greater than the serving base station's received signal strength indication plus a predetermined reselect hysteresis margin (this is a margin applied to the base station reselection to prevent "ping-pong" effects);
2. If the quality of the serving base station's signal is bad and the neighbour base station's signal quality is good and the neighbour base station's received signal strength indication is adequate for service (i.e. exceeds a predetermined threshold defined as being adequate for service); or
3. If the quality of the serving base station's signal is bad and the neighbour base station's signal quality is bad and the neighbour base station's received signal strength indication is greater than the serving base station's received signal strength indication plus the reselect hysteresis margin.

If any of these conditions are true the handover will proceed and the mobile unit will perform the handover attempt as normal. If the handover attempt is successful, the mobile unit should be able to continue

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either with the call or in idle mode with an improved service quality.

5 The reselect hysteresis margin can be determined and selected as desired, for example in the light of practical experience or on the basis of radio (e.g. COSSAP (a digital simulation software package licensed by Synopsis Inc., 700 East Middlefield Road, Mountain View, CA 94043, USA)) simulations. Its value will be a trade-off between reducing the amount of any hysteresis to make the mobile unit more reactive to signal  
10 propagation environment changes and the increase in registration signalling which this may cause as the mobile "ping-pongs" between base stations.

The above preferred embodiment is for a TETRA  
15 system in which the mobile unit makes the handover choice and decision. However, the present invention is equally applicable to other trunked systems, such as GSM (General System Mobile) and UMTS (Universal Mobile Telecommunications System), in which the infrastructure makes the handover decision (and thus can exercise  
20 control over the mobiles, and make decisions based on base site loading, bearer loading, speed of mobile etc.). In such an arrangement, the mobile unit would make the measurements as previously described, but then pass the results up to the base station, so that the  
25 system can make the final handover decision. This is because it is not usually practical in multi-frequency systems for the base stations to make measurements of the signal quality of mobiles in adjacent cells on the up-link channel, as the base stations are busy on their  
30 own frequencies, although special receivers can be added to each base station specifically for this purpose, if desired. Consequently the technique of the present invention would normally be asymmetrical i.e. whatever makes the final handover decision, the mobile units must  
35 make the signal quality measurements.

The method and apparatus of the present invention

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can be implemented in hardware and/or software, as will be appreciated by those skilled in the art. It can be implemented in base stations of a mobile radio communication system and/or in the mobile units of the system to allow those units themselves to control handover. It can be used to control handover of the uplink or downlink or both signals, as desired.

Claims:

1. A method of controlling handover of a mobile radio  
5 unit between base stations in a radio communications  
system, comprising:  
estimating the level of interference on the radio  
channel via which the mobile radio unit is communicating  
with the base station which is currently serving the  
10 mobile radio unit;  
estimating for each of one or more other base  
stations of the system, the level of interference on a  
radio channel available to the mobile radio unit from  
that base station; and  
15 controlling handover of the mobile radio unit from  
its serving base station to the other base station or  
one of the other base stations on the basis of the  
estimated levels of interference on the radio channels  
of the serving base station and the other base station  
20 or stations.
2. A method as claimed in claim 1, comprising  
determining the signal strengths of the serving signal  
and the signal or signals available from the other base  
25 station or stations and controlling handover on the  
basis of the estimated interference levels and the  
determined signal strengths.
3. A method as claimed in claim 2, comprising  
30 attempting to hand the mobile unit over from the serving  
base station to another base station if the signal  
available from the other base station has a greater  
signal strength and no worse an estimated interference  
level than the serving base station signal.
- 35 4. A method as claimed in claim 2 or 3, comprising  
attempting to hand the mobile unit over from the serving

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base station to another base station if the other base station provides a signal strength exceeding a predetermined threshold level and a better estimated interference level than the serving base station.

5

5. A method as claimed in claim 2, comprising controlling handover on the basis of the ratio of the signal strength to the estimated interference level for each signal.

10

6. A method as claimed in any one of the preceding claims, comprising determining whether the interference level and/or the signal strength of the serving base station signal is below a predetermined threshold level, and seeking a handover target if it is determined that the interference level and/or the signal strength of the serving base station signal is below the predetermined threshold level.

20

7. A method as claimed in any one of the preceding claims, comprising comparing the estimated interference levels of the serving and other base stations, and only attempting handover if the other base station's estimated interference level is less than the serving base station's estimated interference level by a predetermined amount greater than zero.

25

8. A method as claimed in any one of the preceding claims, comprising comparing the determined signal strengths of the serving and other base stations, and only attempting handover if the other base station's determined signal strength is more than the serving base station's determined signal strength by a predetermined amount greater than zero.

35

9. A method as claimed in claim 7 or 8, wherein the

value of the predetermined amount varies with the time elapsed since the last handover of the mobile radio unit in a predetermined manner.

5      10. A method as claimed in claim 9, wherein the value of the predetermined amount is increased or decreased by a predetermined amount after a predetermined time period has elapsed since the last handover of the mobile radio unit.

10

11. A method as claimed in any one of the preceding claims, wherein the steps of estimating the level of interference on a radio channel comprise:

15      determining an interference level estimate for each of a plurality of samples of a signal on the radio channel;

    determining the distribution of the values in a set of two or more of the determined interference level estimates; and

20

    estimating the overall interference level of the signal for use in the handover procedure by comparing the distribution of values in the sampled set with one or more predetermined reference distributions of interference level values, each reference distribution representing a particular overall interference level, and making the estimation on the basis of that comparison.

25

12. A method of controlling handover of a mobile radio unit between base stations in a radio communication system, comprising:

30

    determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel via which the mobile radio unit is communicating with the base station which is

35

    currently serving the mobile radio unit;  
    determining the distribution of the values in a set



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of two or more of the determined parameter values;

determining for each of one or more other base stations of the system, the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on a radio channel available to the mobile radio unit from that base station;

determining, for each of the other base stations, the distribution of the values in a set of two or more of the determined parameter values for that other base station; and

controlling handover of the mobile radio unit from its serving base station to the other base station or one of the other base stations on the basis of the determined parameter value distributions for the radio channels of the serving base station and the other base station or stations.

13. A method as claimed in any one of the preceding claims, wherein the interference level estimates comprise the uncoded bit error rate of the signal.

14. A method as claimed in any one of the preceding claims, comprising:

determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

determining the variation of a set of two or more of the determined parameter values; and

estimating the carrier to interference ratio using the determined variation of the set of parameter values.

15. A method as claimed in claim 14, wherein the particular parameter, the variation of which is to be considered, comprises the amplitude of each sample, or a phase measurement relative to the carrier wave for each sample.

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16. A method as claimed in claim 14 or 15, comprising:  
determining plural variation values;  
using each determined variation value as one  
sampled value of the interference level;  
5 determining the distribution of a set of plural  
such variation values; and  
estimating the overall interference level on the  
basis of the determined distribution of the set of  
variation values.
- 10
17. A method of controlling handover of a mobile radio  
unit between base stations in a radio communication  
system, comprising:  
determining the value of a particular parameter for  
15 each of a plurality of samples of a modulated signal on  
the radio channel via which the mobile radio unit is  
communicating with the base station which is currently  
serving the mobile radio unit;  
determining the variation of a set of two or more  
20 of the determined parameter values;  
determining the variation of at least one further  
set of two or more of the determined parameter values;  
determining the distribution of the values in a set  
of two or more of the determined variation values;  
25 determining for each of one or more other base  
stations of the system, the value of a particular  
parameter for each of a plurality of samples of a  
modulated signal on a radio channel available to the  
mobile radio unit from that base station;  
30 determining, for each of the other base stations,  
the variation of a set of two or more of the determined  
parameter values, and the variation of at least one  
further set of two or more of the determined parameter  
values, for that other base station;  
35 determining the distribution of the values in a set  
of two or more of the determined variation values for  
each of the other base stations; and

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controlling handover of the mobile radio unit from its serving base station to the other base station or one of the other base stations on the basis of the determined variation value distributions for the radio channels of the serving base station and the other base station or stations.

18. A method as claimed in any one of the preceding claims, comprising using the estimated interference level for a radio channel to rank the channel as being in one of a plurality of predetermined quality categories.

19. A method as claimed in claim 18, wherein one of the quality categories represents the situation where it is not possible to estimate the channel's interference level.

20. A method as claimed in any one of the preceding claims, comprising estimating the interference levels of the other base stations' channels at regular predetermined intervals.

21. A method as claimed in any one of the preceding claims, comprising determining the channel interference levels of a selected number of the base stations neighbouring the serving base station.

22. A method as claimed in any one of the preceding claims, wherein the interference level estimates and the handover decision are made by the mobile radio unit.

23. A method of controlling handover of a mobile radio unit between base stations in a radio communications system, wherein the handover decision is based on the comparison of corresponding parameter values determined for the signal from the base station which is currently

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serving the mobile radio unit and for radio channels available to the mobile radio unit from one or more other base stations of the system, handover is only attempted to another base station of the system if the  
5 parameter value for that base station is better than the parameter value for the serving base station by at least a predetermined margin, and wherein the value of the predetermined margin is varied with the time elapsed since the last handover of the mobile radio unit in a  
10 predetermined manner.

24. An apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communications system, comprising:  
15 means for estimating the level of interference on the radio channel between the mobile radio unit and the base station which is currently serving the mobile radio unit;  
means for estimating the level of interference on a  
20 radio channel available to the mobile radio unit from another base station of the radio communications system; and  
means for controlling handover of the mobile radio unit between the serving base station and the other base  
25 station on the basis of the estimated levels of interference on the radio channels of the serving and other base stations.

25. An apparatus as claimed in claim 24, comprising  
30 means for determining the signal strengths of the serving signal and the signal or signals available from the other base station or stations and means for controlling handover on the basis of the estimated interference levels and the determined signal strengths.

35 26. An apparatus as claimed in claim 25, comprising means for determining if the signal available from

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another base station has a greater signal strength and no worse an estimated interference level than the serving base station signal and means for attempting to hand the mobile unit over from the serving base station to the other base station in that event.

27. An apparatus as claimed in claim 25 or 26, comprising means for determining if another base station provides a signal strength exceeding a predetermined threshold level and a better estimated interference level than the serving base station and means for attempting to hand the mobile unit over from the serving base station to the other base station in that event.

28. An apparatus as claimed in claim 25, comprising means for controlling handover on the basis of the ratio of the signal strength to the estimated interference level for each signal.

29. An apparatus as claimed in any one of claims 24 to 28, comprising means for determining whether the interference level and/or the signal strength of the serving base station signal is below a predetermined threshold level, and means for seeking a handover target if it is determined that the interference level and/or the signal strength of the serving base station signal is below the predetermined threshold level.

30. An apparatus as claimed in any one of claims 24 to 29, comprising means for comparing the estimated interference levels of the serving and other base stations and for determining whether the other base station's estimated interference level is less than the serving base station's estimated interference level by a predetermined amount greater than zero; and means for attempting handover in that event.

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31. An apparatus as claimed in any one of claims 24 to 30, comprising means for comparing the determined signal strengths of the serving and other base stations and for determining whether the other base station's determined  
5 signal strength is less than the serving base station's determined signal strength by a predetermined amount greater than zero; and means for attempting handover in that event.

10 32. An apparatus as claimed in claim 30 or 31, comprising means for varying the value of the predetermined amount with the time elapsed since the last handover of the mobile radio unit in a predetermined manner.

15 33. An apparatus as claimed in claim 32, wherein the value of the predetermined amount is increased or decreased by a predetermined amount after a predetermined time period has elapsed since the last  
20 handover of the mobile radio unit.

34. An apparatus as claimed in any one of claims 24 to 33, wherein the means for estimating the level of interference on a radio channel comprise:

25 means for determining an interference level estimate for each of a plurality of samples of a signal on the radio channel;

means for determining the distribution of the values in a set of two or more of the determined  
30 interference level estimates; and

means for estimating the overall interference level of the signal for use in the handover procedure by comparing the distribution of values in the sampled set with one or more predetermined reference distributions  
35 of interference level values, each reference distribution representing a particular overall interference level, and making the estimation on the

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basis of that comparison.

35. An apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communication system, comprising:

- 5       means for determining the value of a parameter indicative of signal quality for each of a plurality of samples of a signal on the radio channel between the mobile radio unit and the base station which is
- 10      currently serving the mobile radio unit;
- means for determining the distribution of the values in a set of two or more of the determined parameter values;
- means for determining the value of a parameter
- 15      indicative of signal quality for each of a plurality of samples of a signal on a radio channel available to the mobile radio unit from another base station of the radio communications systems;
- means for determining the distribution of the
- 20      values in a set of two or more of the determined parameter values for the other base station; and
- means for controlling handover of the mobile radio unit between the serving base station and the other base station on the basis of the determined parameter value
- 25      distributions for the radio channels of the serving and other base stations.

36. An apparatus as claimed in any one of claims 21 to 28, wherein the means for estimating the interference

30      level on a radio channel means for measuring the uncoded bit error rate of the signal.

37. An apparatus as claimed in any one of claims 24 to 36, comprising:

35      means for determining the instantaneous value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel;

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means for determining the variation of a set of two or more of the determined parameter values; and

means for estimating the carrier to interference ratio using the determined variation of the set of parameter values.

38. An apparatus as claimed in claim 37, comprising:  
means for determining plural variation values;  
means for using each determined variation value as one sampled value of the interference level;  
means for determining the distribution of a set of plural such variation values; and  
means for estimating the overall interference level on the basis of the determined distribution of the set of variation values.

39. An apparatus for controlling handover of a mobile radio unit between base stations in a mobile radio communication system, comprising:  
means for determining the value of a particular parameter for each of a plurality of samples of a modulated signal on the radio channel between the mobile radio unit and the base station which is currently serving the mobile radio unit;  
means for determining, for each of two or more sets of two or more of the determined parameter values, the variation of the determined parameter values in the set;  
means for determining the distribution of the values in a set of two or more of the determined variation values;  
means for determining the value of a particular parameter for each of a plurality of samples of a modulated signal on a radio channel available to the mobile radio unit from another base station of the radio communications systems;  
means for determining, for each of two or more sets of two or more of the determined parameter values for



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the other base station, the variation of the determined parameter values in the set;

5 means for determining the distribution of the values in a set of two or more of the determined variation values for the other base station; and

10 means for controlling handover of the mobile radio unit between the serving base station and the other base station on the basis of the determined variation value distributions for the radio channels of the serving and other base stations.

40. A mobile radio unit comprising the apparatus of any one of claims 24 to 39.

15 41. An apparatus for controlling handover of a mobile radio unit between base stations in a radio communications system, comprising means for basing the handover decision on the comparison of corresponding parameter values determined for the signal from the base  
20 station which is currently serving the mobile radio unit and for radio channels available to the mobile radio unit from one or more other base stations of the system, means for attempting handover to another base station of the system if the parameter value for that base station  
25 is better than the parameter value for the serving base station by at least a predetermined margin, and means for varying the value of the predetermined margin with the time elapsed since the last handover of the mobile radio unit in a predetermined manner.

30

42. Computer software specifically adapted to carry out a method as claimed in any one of claims 1 to 23 when installed on data processing means.

35

43. A computer software carrier comprising software as claimed in claim 42.

1 / 4

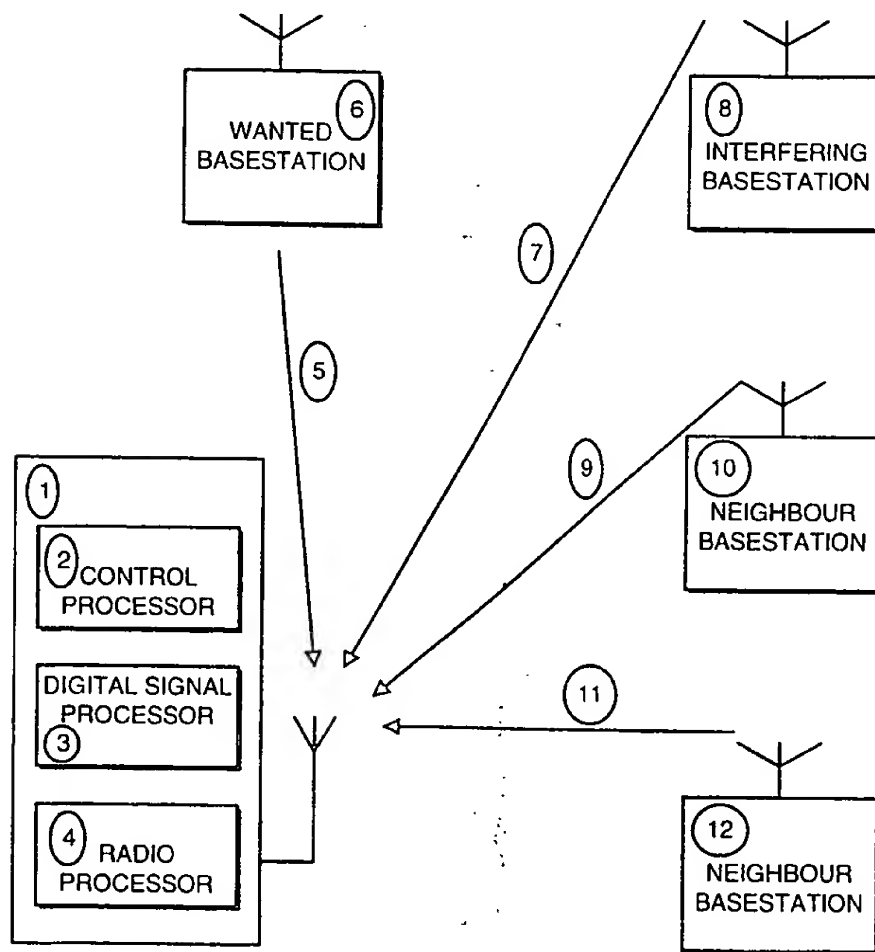


FIG. 1

2 / 4

FIG. 2

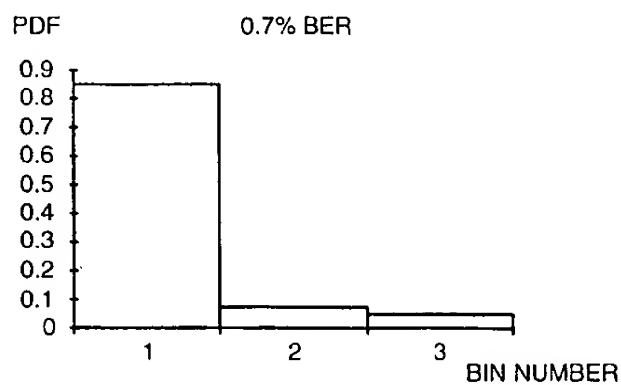


FIG. 3

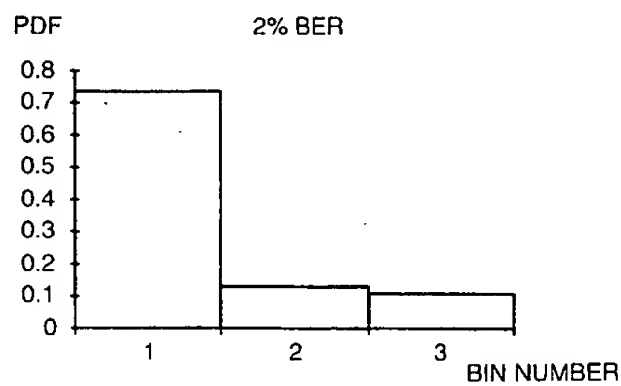
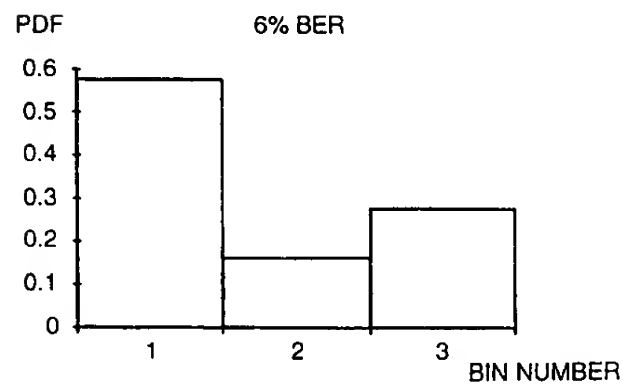


FIG. 4



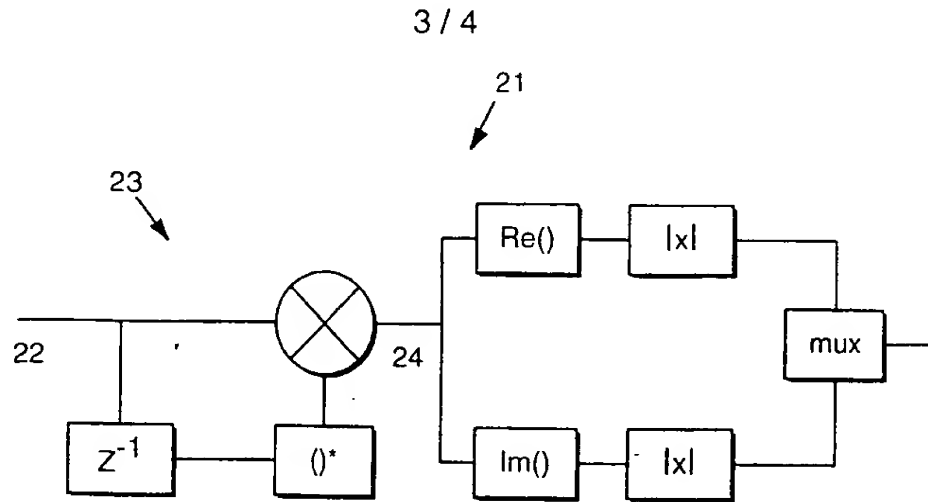
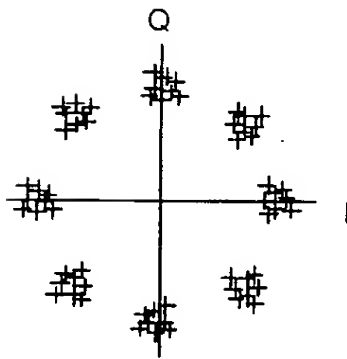
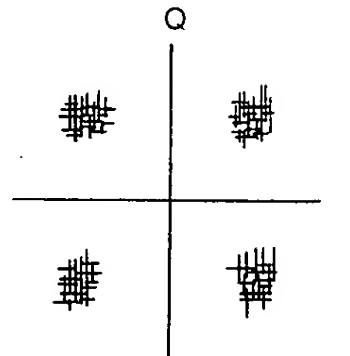


FIG. 5



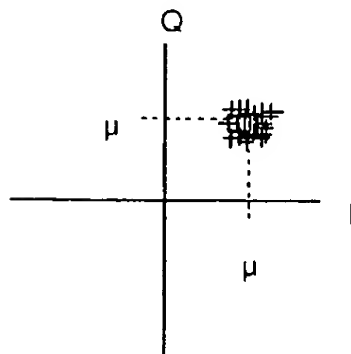
MODULATED PI/4DQPSK  
TETRA SIGNAL

FIG. 6



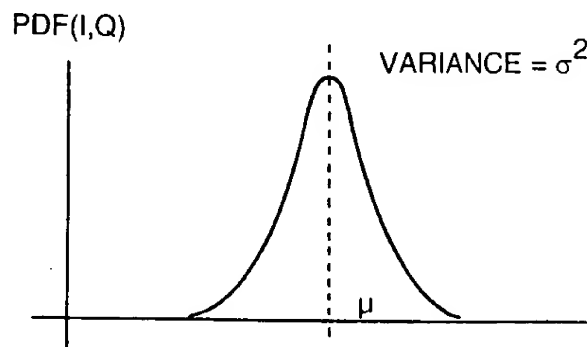
DEMODULATED PI/4DQPSK  
TETRA SIGNAL

FIG. 7



CONSTELLATION POINTS  
MAPPED TO 1st QUADRANT

FIG. 8



PDF OF CONSTELLATION  
POINTS

FIG. 9

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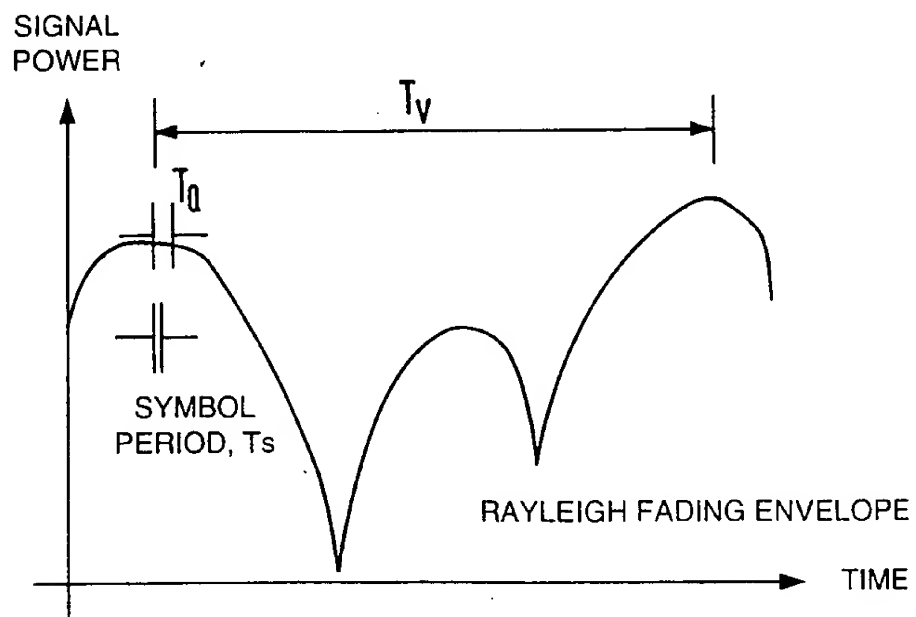


FIG.10

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/01534

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 752 190 A (KAEWELL JR JOHN D ET AL) 12 May 1998 (1998-05-12) column 1, line 46 - line 64  column 2, line 52 - column 3, line 14 column 3, line 63 - column 4, line 16	1, 2, 21, 24, 25 3-8, 26-31
X	WO 95 28808 A (NOKIA TELECOMMUNICATIONS OY ;AALTO RISTO (FI)) 26 October 1995 (1995-10-26) page 2, line 33 - page 4, line 11 page 9, line 12 - page 11, line 17 page 16, line 19 - page 17, line 8  -/--	1, 2, 24, 25

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"Z" document member of the same patent family

Date of the actual completion of the international search

1 September 1999

Date of mailing of the international search report

08/09/1999

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Barel, C

# INTERNATIONAL SEARCH REPORT

Inter. nal Application No

PCT/GB 99/01534

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	PREM DASSANAYAKE: "DYNAMIC ADJUSTEMENT OF PROPAGATION DEPENDENT PARAMETERS IN HANDOVERALGORITHMS" PROCEEDINGS OF THE VEHICULAR TECHNOLOGY CONFERENCE, STOCKHOLM, JUNE 8 - 10, 1994, vol. 1, no. CONF. 44, 8 June 1994 (1994-06-08), pages 73-76, XP000496637 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS the whole document ---	12
A	the whole document ---	17
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A	WO 97 32445 A (ERICSSON TELEFON AB L M) 4 September 1997 (1997-09-04) page 8, line 2 - page 10, line 23 page 15, line 19 - page 16, line 29 page 32, line 3 - page 35, line 31 figures 7,8 -----	12,17, 35,39

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 99/01534

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